REPORT ON THE

POST-2002 MISSION PLANNING WORKSHOP

Easton, Maryland

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NASA Earth Science Enterprise

Report prepared by

Dr. Charles Kennel
Dr. Edward Frieman
Dr. Berrien Moore
Dr. Lisa Shaffer

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Section 1:
INTRODUCTION AND BACKGROUND

Perspective

Over the next century, an international observing system that supports the science and policy of the global environment will be designed and operated. The need has emerged from the implications of scientific work that started some time ago. The possibility of global changes in the physical, chemical, and biological environment had been recognized in the nineteenth century and became a widely accepted idea in the twentieth. By the mid-1970 s, there had emerged specific concerns which affect every nation, every decision entity, and every person on the globe; among them, stratospheric ozone depletion, climate change and greenhouse warming, and threats to the world s ecosystems and biodiversity.

The first institutional response came in the next decade. The World Meteorological Organization and other international bodies convened major world climate conferences in 1979 and 1989. From these and other meetings there emerged the conclusion that the implications of climate change should be assessed for development policy. In 1988, the Intergovernmental Panel on Climate Change, composed of hundreds of scientists from more than 50 countries, assumed responsibility for international assessments of climate change and its consequences. The Montreal Protocol on the limitation of ozone-destroying substances in the stratosphere was also signed in 1988. By this time, it was recognized that addressing the issues of global change entails an extraordinary integration of scientific work across numerous disciplines. The US Global Change Research Program (USGCRP) was created in 1990 to promote the necessary interdisciplinary integration in US agency programs. The World Climate Research Program and the International Geosphere-Biosphere Program were designed to play an integrating role at the international level.

The need to acquire multidisciplinary data and information on a global scale was recognized in these scientific and policy deliberations. Beginning in the mid-1980 s, international scientific and operational groups began to propose conceptual designs of systems that address one or more of the components of the global environment. These plans, misleadingly called systems, include the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS). The critical, if not dominant role, is played by remote sensing from space in all these plans. NASA s Earth Observing System was designed and funded as the cornerstone of the observational strategy of the USGCRP and related international efforts within the framework of an International Earth Observing System (IEOS) involving the efforts of several international partners. While IEOS did not develop as originally foreseen, it stimulated a broader look at observations from space and related in situ measurement strategies.

The Committee on Earth Observation Satellites (CEOS) was created in 1984 to coordinate space remote sensing programs at the international level, and now has eighteen space agencies as members. In 1992 for the United Nations Conference on Environment and Development, CEOS disseminated a detailed summary of the schedules and specifications of all the existing and planned Earth observing instruments to be flown in space. This was updated in 1995 and 1997, and complemented by a preliminary set of prioritized observing requirements from the three Global Observing System groups and other relevant global Earth science programs. CEOS agencies recognized that no science problem has been solved by space measurements alone, and nearly all space measurements require complementary measurements taken in situ. With this awareness, CEOS, led by Japan and the US, then called for an Integrated Global Observing Strategy (IGOS), to link space and in situ observations in a common strategic framework.

The broad outlines of what must be achieved by an Integrated Global Observing Strategy are clear. Scientific understanding is evolving; observational technology is evolving; new applications are being created; new policy issues are certain to emerge. Thus, the strategy must be designed to accommodate change. The strategy must address numerous scientific and practical objectives simultaneously. The strategy needs to encourage a seamless relationship between research and monitoring. The strategy must preserve the continuity of essential long-term measurements while responding to changing scientific and practical needs in the short term. The strategy must deal with space and in situ observations together. In the case of climate, the observing strategy will be designed and evaluated in the light of global numerical models, and must be responsive to policy issues raised by such groups as the Intergovernmental Panel on Climate Change. The strategy must promote broad international participation: to share costs; to secure adequate geographical coverage; and, most important, to build confidence among global decision-makers in the conclusions drawn from the use of the observations. The strategy cannot avoid dealing with the essential institutional issue of time scales. We must create decision processes that can endure for the times needed to document slow changes in the global environment, during which time political, practical, and scientific priorities will necessarily change.

Above, in brief outline, is the context in which the evolution of the Earth Observing System since its beginning in the planning efforts of the 1980 s should be viewed. The present evaluation of its most recent evolutionary step can only be understood in light of past developments in science, policy, and observing strategy.

How the Earth Observing System Has Evolved

The Earth Observing System (EOS) has been a cornerstone of the US Global Change Program since its inception in 1990. The initial proposal for EOS, never implemented, was for two very large, multi-instrument, multidisciplinary platforms, EOS-A and EOS-B, to be launched by the space shuttle into morning and afternoon sun synchronous polar orbits. Identical copies of each platform were to be launched at five-year intervals so as to secure a 15-year comprehensive and continuous data set on the Earth system. It was thought fundamental to observe each spot on the Earth with a full array of Earth system science instruments simultaneously. The high cost of shuttle launches, the size and complexity of many of the proposed instruments, and the difficulty of integrating numerous instruments with conflicting requirements on the same platform were some of the reasons that the basic architecture of EOS was modified in 1992. At that time, it became clear that some of the proposed measurements could not be made economically with the technology available at the time; directed technology development to reduce the size and complexity of these instruments would be needed. Furthermore, not all the instruments needed to be used at the same time; ocean and land measurements would be made at different times. Thus, the remaining measurements could be separated with little loss of science content into three less complex missions plus a number of smaller ones. The three were EOS-AM1, which focuses on land measurements made from a morning orbit, EOS-PM1, devoted to climate and meteorology related measurements from an afternoon orbit, and EOS-CHEM, for tropospheric and stratospheric chemistry measurements. The basic comprehensiveness of the original EOS-A and B data sets was maintained by the addition of several smaller missions. These basic steps, and the delay in the launch dates for EOS PM1 and CHEM1, reduced the 15-year cost of EOS from $17B to about $8.5B.

The basic architecture established in the 1992 NASA review was implemented; EOS-AM1 will be orbited by an Atlas launch vehicle within the year, and EOS-PM1 and EOS CHEM1 are scheduled for launch in 2000 and 2002, respectively. Since for these missions there was more time to adopt the new smaller instrument approach, EOS-PM1 and EOS-CHEM1 could be launched using the smaller Delta rocket. A year later, WHEN THE PREVIOUS NASA-DOD partnership for Landsat collapsed, the Landsat-7 mission was added to EOS, without a compensating increase in funding. These spacecraft, plus certain ancillary flights, define the so-called first round of EOS.

NASA s implementation philosophy continued to evolve as its understanding of the EOS mission advanced. NASA recognized that the main cost-driver of the system was instrument size, which drove spacecraft and launch vehicle requirements. It began to be clear that reflight of the identical instruments on identical repeats of the same missions would not capture the cost savings and/or performance enhancements foreseeable with directed technology development. This was one of the primary issues reviewed at the La Jolla Workshop on EOS implementation conducted in 1995 by the Committee on Global Change Research as a prelude to its Pathways report.

The generally prevailing ideas on how to secure continuous data sets had proven to be too restrictive in the EOS context; NASA declared that the implementation of the second and third rounds should allow technological evolution in both instruments and spacecraft. NASA would of course need to invest in those activities, such as ground validation and instrument intercalibration, which relate the data sets taken by differing instruments with the same measurement objective. Although how the measurements were made would change, the basic types of measurements to be made would not, and NASA committed to collecting 24 basic data sets over (now) 18 years. In recognition of the need to continuously evolve EOS technology, NASA, led by the Goddard Space Flight Center, which was named as the lead center for the EOS program, committed to reviewing EOS implementation every two years, approximately the interval between major EOS launches. Putting these changes into place again reduced the cost of EOS, and thereafter congressional funding for EOS stabilized somewhat.

The complete 1998 Pathways report examined the development of all of global change science. It concluded that the EOS missions could and should be more clearly focussed on the key scientific issues that had emerged over the past ten years; furthermore, new scientific issues clearly require some new types of measurements. Thus, NASA concluded that both the scientific objectives and the technical implementation of EOS should evolve.

Time is short, but it is still possible to change the design and implementation of the second round of EOS. The challenge is to decide, in advance of the flight of AM1, but in light of knowledge gained, which data sets should be continued into the second round, and which should be de-emphasized to make room for new scientific objectives, so that EOS may be executed within its slowly declining cost envelope. The process NASA has set in motion to decide what to do, and the conclusions reached thus far, are the subjects of this report. The Request for Information (RFI) process that NASA has set in motion (described in the following section), the disciplinary reviews (section 5) and the present Interdisciplinary Panel Review conducted at a workshop in Easton, Maryland, on August 24-26 are the subjects of this document. NASA has made some adjustments to its plans on the basis of the discussions at the meeting of the Interdisciplinary Panel. The decision process will continue with a review by a special panel of the National Academy of Sciences/National Research Council.

The question of the long-range future of the measurement series initiated by EOS surfaced at the Easton workshop. This issue will necessarily dominate the next scientific review of EOS in five years, when the third round of EOS will be defined. How shall the measurements of importance to science and public policy be continued beyond the third round? At the present time, the most critical part of the debate focuses on the transition of certain EOS instrumental capabilities to the National Polar-Orbiting Environmental Satellite System (NPOESS) in 2009, but the overall issue is much broader than that. There is no policy framework for discussing the post-EOS era of remote sensing observations for Earth System Science. We will offer some preliminary thoughts on this important issue at the end of our report.

Section 2:
THE NASA PROCESS

The Earth Observing System (EOS) satellite missions AM1, PM1 and CHEM1, were conceived for broad-scope data gathering (as required for exploratory investigation in a wide field of Earth science) and, simultaneously, to provide a baseline for long-term global environmental monitoring from space. While the scientific objective of NASA - understanding the Earth environment as a fully interactive system - has not varied, budget limitations, changes in technology, and advancements in scientific understanding call for a review of the strategy to pursue this goal in the next decade, beyond the first series of EOS missions. In issuing a "Request for Information" to the Earth science community in 1998, NASA's Earth Science Enterprise (ESE) sought first to re-validate the linkage between its overall scientific goal - expanding knowledge of the Earth system - and the existing EOS measurement strategy, and, second, to identify emerging new research priorities. The "Request for Information" process is a new administrative procedure to involve, as directly and quickly as practicable, a wide range of investigators and partners in the conception of strategic plans for future NASA flight programs. This process is not intended as a one-time opportunity, but rather as the first of a series of consultations: the ESE intends periodically to refresh this planning process through similar consultations with the Earth system science and applications communities at appropriate intervals in the future.

The primary focus of the "Request for Information" (RFI) was to construct a nominal mission scenario, based on responses received to the "Request" and reflecting the scientific priorities formulated by national institutions (National Academy of Sciences/National Research Council) and international scientific bodies, such as the World Climate Research Program and the International Geosphere-Biosphere Program. NASA informed RFI respondents of its intent to promote a program of smaller satellite missions, with a shorter implementation cycle from inception to launch in order to allow faster response to new research priorities and to reduce the risk to overall program objectives from any single mission failure. *Smaller missions imply more focused mission objectives*, targeting specific scientific questions beyond the anticipated achievements of the first series of EOS and Earth Probe missions, as recommended explicitly in the "Research Pathways" report of the Committee on Global Change Research of the National Academy of Sciences. Advances in modeling of the interactive Earth system provide confidence that this strategy of simpler global observing projects, focused on narrower and more coherent science objectives, can still support the goal of the U.S. Global Change Research Program to embrace the full interdisciplinary range of Earth science research issues and understand the behavior of the Earth environment as a system.

<u>The Request For Information Procedure</u>

The purpose of the RFI process was to seek new ideas for space-based investigations and measurement concepts, to further develop the observation program initiated with the first series of EOS missions, and to take advantage of progress in instrument, spacecraft and information technology for further scientific advances and new applications within a lower cost profile. The RFI stated that the primary criterion for assessing the priority of new missions would be the significance of their scientific objective, and the maturity of technologies that would enable them.

One hundred responses were received. Step 1 of the RFI process involved scientific reviews by six panels covering complementary domains of Earth system science and applications:

- Atmospheric Chemistry
- Atmospheric Climate Physics
- Global Water Cycle, Hydrology and Mesoscale Weather
- Ocean and Ice
- Land cover, land use and terrestrial ecosystems
- Geodynamics and Geology

A survey of emerging science priorities by each of these disciplinary panels led to highlighting 23 mission concepts that were recommended for further technical and cost assessment. The mission concepts are described in the RFI Step 1 Briefing Book **[http://www.hq.nasa.gov/office/ese/nra/RFIdodge/Panelrev.html]**, together with a summary of science priorities identified by the Step 1 review panels. Twenty-two mission concepts were actually analyzed by NASA technical staff and an industrial contractor. (One mission concept - Earth magnetic field monitoring - could be pursued through NASA participation in satellite missions of opportunity led by international partners.) Implementation costs were estimated on the basis of a standard "cost model" based on the experience of similar past or current satellite missions; instrument development costs were estimated on the basis of data provided by RFI respondents and prospects offered by technology advances. Taking into account mission cost estimates and programmatic prospects for the Earth Science Enterprise, the mission concepts were consolidated into a nominal "mission scenario" for the period 2002-2010.

The nominal mission scenario and underlying programmatic guidelines were presented to a Post-2002 Mission Planning Workshop, held in Easton, MD (24-26 August 1998). The objective of the Workshop was to allow interactive discussions of the mission scenario by a representative group of RFI respondents and an Interdisciplinary Review Panel of independent scientific experts. This report completes the RFI process. The outcome of this strategic planning process will be provided to the National Academy of Sciences for its review. ESE will be guided by the recommendations of both the Interdisciplinary Panel from the Easton Workshop (this report) and the Academy in planning future flight missions.

Three Categories of Missions

In order to define more clearly the implementation procedures and constraints, in conformity with new guidelines adopted by the Enterprise, three distinct categories of missions were defined:

- **EOS follow-on missions** for systematic measurement of critical parameters.

- **Earth Probe missions** for exploratory research or focused process-studies.
- **Pre-operational Instrument Developments** to provide new or more capable sensors for operational observing systems.

The three components of the program are briefly described below and in the NASA report (known as the Blue Book) which is provided in its entirety as Appendix 1.

1. Systematic Measurement Missions

The first objective of NASA Earth Science Enterprise is to fulfill its commitment to the science community to maintain continuity of EOS measurements of critical Earth system parameters, and deliver consistent time series of global measurements over the period of time effectively required. The nominal plan of ESE is to meet this commitment within a sustained level of funding about 30% lower than comparable elements in the first EOS series.

In order to achieve this goal, NASA intends (1) to identify essential parameters requiring systematic measurement *from an Earth system science perspective* and (2) promote to the extent possible the convergence of its global observation program with the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. Appropriate bridging missions are identified in the nominal scenario to ensure measurement continuity in the interim period until operational observing systems deliver the required information. Further, NASA intends to promote, to the extent possible, cooperation with private sector and international partners to implement joint projects that can provide research-quality global observations. The nominal plan mandates an evolution toward dedicated missions, each carrying a much simpler payload designed to provide a coherent set of measurements for a single primary science theme. The ESE will capitalize on infusion of advanced technologies to optimize instrument and platform design, and minimize new mission costs.

2. Discovery and Process-research Missions

Based on the assumption made above and estimated experimental mission costs, the nominal scenario would allow the implementation of a multi-disciplinary Earth Probe program (incorporating the Earth System Science Pathfinder program) including one discovery and process-research mission launch every nine months, beginning in 2004. The Enterprise did not commit to a set program of experimental satellite missions for the next ten years. The intent is to issue successive solicitations for proposals to implement comprehensive missions that address specified science themes. NASA will determine step by step the sequence of scientific disciplines addressed by the Earth Probe program, upon confirmation of scientific priorities by scientific institutions and bodies, consideration of technical and funding capabilities, and determination of opportunities for international cooperation.

3. Pre-Operational Instrument Developments

Implicit in the planning strategy outlined above for systematic global observations is the assumption that NASA will invest sufficient effort to enable operational Earth observation programs, such as NPOESS and GOES, to provide long time-series of consistent, research-quality measurements. The procedure to achieve the desired convergence and establish effective arrangements for joint participation in the development of these prototype operational sensors is being worked at the present time. NASA indicated readiness to invest in the development and/or flight demonstration of advanced observing capabilities that meet operational needs as well as long-term Earth science objectives, when such projects are supported by a commitment of responsible operational agencies to participate in the development of the new sensors, and to implement their transition to operational use. The ESE would insert such pre-operational instrument developments into its flight mission program by re-ordering mission priorities in the systematic measurement, discovery or technology demonstration components (New Millennium Program) of the nominal mission scenario.

Section 3:
THE EASTON WORKSHOP

The Easton Workshop consisted of discipline-focused panels and an interdisciplinary review panel. Experts were invited in the fields of atmospheric chemistry, atmospheric climate and water cycle, oceanography (including ecosystems) and polar, land cover and terrestrial ecosystems, geology and natural hazards/applications. They were joined by observers from other U.S. Government agencies (FEMA, NOAA, FEMA, NSF, USGCRP, OMB, NPOESS IPO) and non-U.S. organizations (DLR, CNES, CSA, ESA, NASDA, EUMETSAT, and the Brazilian Space Agency). A list of invitees is included as Appendix 2.

The agenda is provided in Appendix 3. The purpose of the workshop was to review candidate missions and mission scenarios for the period 2002-2010. The workshop was called upon to formulate recommendations to NASA regarding the balance between research disciplines in Earth system science, systematic measurements and exploratory research, science-driven programs and technology development or demonstrations.

The workshop began with overviews of the program, implementation process, and RFI process and nominal mission scenario. Chairpersons of the six Step 1 Review Panels summarized the emerging Earth system science questions identified in their respective disciplines, and the conclusions they reached concerning measurement and mission priorities in the next decade. Disciplinary groups then reviewed the nominal mission scenario in the light of science or application priorities in their respective disciplines and formulated views or recommendations regarding the balance of the nominal mission scenario. Breakout groups were formed for atmospheric chemistry, atmospheric climate and global water cycle, ocean and ice, land cover and terrestrial ecosystem research and applications, and geology, natural hazards and applications for consideration of the proposed new strategy and nominal mission scenario. The new chairpersons of these groups led the discussions, made notes, and viewgraphs, and presented their results in plenary. Their reports are given in Appendix 4. The Interdisciplinary Panel was asked to take a "broad, across-the-board" look at the plans and to endorse or recommend modifications to the strategy. Due to the magnitude of the task and the short time available in Easton, the interdisciplinary experts met, but chose to prepare their report via written inputs provided after the workshop. These summaries, provided in Appendix 5, address areas of agreement and describe issues and areas for further attention, as well as defining priorities in some cases. It is these contributions which form the basis for the recommendations and conclusions of this report.

Section 4:
THE NOMINAL MISSION SCENARIO

As a result of the process described above, NASA produced the ESE Mission Scenario for the 2002-2010 Period. This scenario defines and proposes three types of mission concepts: EOS follow-on missions for data continuity, Earth Probe exploratory missions for discovery and process-oriented research, and operational instrument development projects to demonstrate candidates for long-term operational systems. Figure 1 summarizes this nominal mission scenario, which is explained in the Blue Book at Appendix 1.

The previous baseline dated April 15, 1997, before the Biennial Review that NASA undertook in the summer of 1997, shows the following missions in chronological order, with their follow-ons where such existed:

Mission	Launch Date	Follow-on	Launch Date
TRMM	6/97	TBD/ATMOS-A	
		CERES mid-incl FOO	2000
ACRIM	1998	TSISat	2001
AM-1	6/98	AM-2, incl LATI NMP EO-1 (99)	6/04
Landsat-7	9/98		
SAGE-3 on Meteor	6/98	SAGE-3 on Station	2001
		SAGE-3 mid-incl. FOO	2005
ADEOS-2/Seawinds	2/99	TBD (Metop?)	
Jason-1/Radar alt	1999	Radar-alt-2	2004
PM-1	12/00	PM-2	12/06
		NOAA-N	2007
Laser Alt-1	7/02	Laser Alt-2	7/07
SOLSTICE	12/02	SOLSTICE FOO	2008
CHEM-1	12/02	CHEM-2 Monitor (includes SAGE-3)	6/08
		CHEM-2 Process	12/08

Figure 1: Pre-RFI Mission Scenario

The Blue Book scenario does not alter the missions shown in the first column. However, it addresses an evolution in the approach to defining the follow-ons which was already foreseen with the Chemistry mission, where CHEM2 was divided into a monitoring mission and a process mission with different objectives, different payloads, and different launch dates. Displaying the follow-on column from the table above against the Blue Book nominal scenario shows the evolution. The table below does not address new exploratory/discovery missions in areas not previously addressed in the EOS scenario, i.e., gravity, soil moisture, ocean salinity, vegetation recovery, and cold land processes, nor the proposed approach for development of operational instruments.

Figure 2
Comparison of Mission Scenarios for Data Continuity

Mission	**Launch Date**	**Previous follow-on mission concept**	**Launch Date**	**Blue Book concept & dates**	
TRMM	6/97	TBD/ATMOS-A		Int l Precip. Mission (03)	EOS-9 Global Precip. Mission (09)
		CERES mid-incl FOO	2000		
ACRIM	1998	TSIsat	2001	EOS-4 TSIM (01)	TSI (04)
AM-1	6/98	AM-2 incl. LATI NMP EO-1 (99)	6/04	EOS-3 Land & Ocean Imaging (04)	
Landsat-7	9/98			EOS-1 Land Cover Inventory (04)	
SAGE-3 on Meteor	6/98	SAGE-3 on Station	2001	EX-2 Aerosol Radiative Forcing Research Mission	
		SAGE-3 mid-incl. FOO	2005		
ADEOS-2/Seawinds	2/99	TBD (Metop?)		EOS-5 METOP 1-3 (03), NPOESS (09)	
Jason-1/Radar alt	1999	Radar-alt-2	2004	EOS-6 NPOESS Alt (09)	
PM-1	12/00	PM-2A	12/06	AIRS & AMSU — EOS-2 Climate Variability (06)	
		NOAA-N	2007	NPOESS (09)	
Laser Alt-1	7/02	Laser Alt-2	7/07	EOS-10 Icesat-1 (01)	Icesat-2 (10)
SOLSTICE	12/02	SOLSTICE FOO	2008		
CHEM-1	12/02	CHEM-2 Monitor (includes SAGE-3)	6/08	EOS-7 Strat-CHEM/ISS (04)	Strat-CHEM (08)
		CHEM-2 Process	12/08	EX-1 Tropospheric Chemistry (at least 1 & ideally 2 missions)	
ERS-1,2				Envisat ASAR (00)	
Radarsat-1		Radarsat-2	2000	EOS-8 Experimental SAR (02)	

Section 5:
SUMMARY OF DISCIPLINE PANEL INPUTS

This section summarizes the reports from discipline-focused experts in Easton, reviewing the Step 1 results and nominal Blue Book scenario. These reports were the inputs to the Interdisciplinary Panel whose recommendations follow in Section 6.

Atmospheric Chemistry

The disciplinary group reiterated the conclusions of the Step 1 Panel, which were incorporated for the main part in the nominal flight mission plan. They agreed in particular with a strategy based on systematic measurements of a limited range of key constituents in the stratosphere, and broad, discovery-type, experimental missions for investigating tropospheric chemistry. The gist of their recommendation addressed issues not related to flight missions, such as inter-disciplinary linkages (with Atmospheric Physics, in particular) and the need for a comprehensive research plan combining optimally in situ measurements with satellite observation, global data analysis with modeling, professional investigator research with student involvement. They also expressed concern about the capability of the NPOESS program to fully embrace research-quality measurement objectives.

Atmospheric Physics, Global Water Cycle and Hydrology

This group supported in essence the conclusions of the two independent Step 1 Panels that addressed Atmospheric Radiation Research and Basic Atmospheric Variables on the one hand, and Hydrology/Mesoscale Weather Research on the other. The group based its recommendations on the Blue Book and highlighted only three substantial issues:

- The group questioned ESE's assumption that Japan would lead a global precipitation mission as a follow-on to TRMM in the first half of the next decade and recommended the Global Precipitation Measurement Mission be advanced in time to the 2003 time-frame.
- The group recognized that similar low-frequency microwave radiometry techniques could be applied to estimate soil moisture (or wetness) and sea surface salinity, but recommended that NASA not delay an experimental mission aimed soil moisture until the more demanding needed to measure ocean salinity could be achieved.
- The group indicated its support for an Experimental Geostationary Research Mission suitable, in particular, for mesoscale meteorological studies but failed to identify specific research objectives in this domain.

Ocean and Ice

The disciplinary group considered the nominal mission scenario in the light of the priorities laid out by the Step 1 Panel, and focused its attention on specific discrepancies.

- The group supported the first priority given by the Step 1 Panel to the continuity of systematic global ocean topography measurements and questioned the feasibility of achieving scientifically adequate precision with altimetric measurements from low-altitude polar platforms. Further, the group noted that the first NPOESS mission that may accommodate a radar altimeter (5:30 am equator crossing time) will not fly in the next decade, owing to the number of DMSP spacecraft yet to be used on this orbit. Under these circumstances, the group expressed concern that a large data gap will occur in this fundamental oceanic record between the end of the Jason-1 mission and the first possible NPOESS replacement.

- The group highlighted the significance of ocean-surface (vector) wind measurements and recommended that NASA continue the Seawinds program on a follow-on mission after ADEOS-2

- The group regarded the continuity of systematic ocean color measurements the third highest priority for ocean sciences, agreed that the Advanced Global Imager sensor proposed in the nominal scenario could provide adequate baseline measurements, but and questioned the possibility of obtaining research-quality data from NPOESS in early morning and afternoon orbits.
- The group highlighted the significance of global salinity data to understand the world ocean circulation and supported the concept of an experimental ocean salinity-measuring mission.

- The group endorsed the incorporation of systematic precision altimetry measurements in the nominal scenario but recommended that such observation be maintained continuously.

- The group recommended programmatic coordination with NOAA/NESDIS to allow the development of new sensors, such as the Special Event Imager, on operational geostationary satellites.

Land Cover and Terrestrial Ecology Research

The land group generally supported the provisions made in the nominal scenario to maintain the continuity of two essential data records for global land cover inventory (Landsat follow-on) and global ecosystem productivity (medium-resolution multi-spectral imaging) missions. The group further supported the priority given to experimental observation of ecosystem response to natural and anthropogenic disturbances. However, the group recommended that a more ambitious range of co-registered active (lidar), hyperspatial (1 meter-class imaging), multi-angular and hyperspectral observation be considered for the experimental "ecosystem response" mission.

In general, the group emphasized the importance of nurturing interdisciplinary ecosystem science through a comprehensive program capable of integrating data from a variety of sources, including commercial observing systems. These concerns will be taken into account of the NASA science plan.

Solid Earth, Natural Hazards and Applications

The disciplinary group was generally able to endorse the nominal mission scenario, as part of a broader comprehensive research strategy integrating in situ observation, with some specific recommendations:

- The group considered that the scientific return of a (transient) gravity field mapping mission justifies continuation as a systematic measurement.

- The group emphasized the importance of an Experimental Geostationary Research Mission, in particular for the research on rapidly evolving processes and the development of sensors for natural hazard warning applications.

In general, the group felt that all missions considered in the nominal scenario should be optimized to serve application objectives.

Section 6:
SUMMARY OF INTERDISCIPLINARY PANEL INPUTS

Analysis of the comments and recommendations of the interdisciplinary panel at the Easton workshop shows that, with a few exceptions, there is general agreement with the NASA Blue Book nominal mission scenario. Participants expressed overarching concerns about the long-term continuity of critical observations; the adequacy of NPOESS to meet scientific requirements in certain areas; the need for increased attention to data integration across missions and between space-based and in situ observations; facilitation of interdisciplinary research; and the need for increased attention to applications uses of the data and information from the NASA ESE program. These concerns are summarized in Section 8.

Significant issues concerning the nominal mission scenario are summarized below.

Atmospheric Climate Physics

This group had strong agreement with the nominal scenario.

- The panel supported the systematic measurement missions (EOS-2 Climate Variability and Trend; EOS-4 Total Solar Irradiance Monitoring), exploratory missions (EX-2 Aerosol Radiative Forcing Feedback; EX-3 Cloud Radiation Feedback), and preoperational instrument (OP-2 Tropospheric Wind Sounder) described in the Blue Book.

- They noted the importance of a geostationary program, and called for further study in this area.

- One recommendation is the addition of a wind measurement capability on EOS-2 with inclusion of a tropospheric wind profiler or planning a flight of an incoherent detection Doppler lidar system at the same time.

- They call for careful and extensive coordination with national and international partners and across different missions to maximize the return for the community.

Applications

- The Panel endorsed the continuity of systematic measurements at high and moderate resolution (EOS-1 and EOS-3) as well as continued ocean productivity with the Advanced Global Imager.

- The Global Precipitation Mission (EOS-9) was strongly endorsed with an equally strong recommendation that it be accelerated and worked with international partners.

- The Applications group endorsed OP-6, the Special Events Imager.

Oceans and Ice

- The Oceans and Ice interdisciplinary panel affirmed the essential elements of the report from the Ocean and Ice Technical Panel.

- The highest priority for the scientific missions during the 2002-2010 period is maintaining continuity and information content in the several critical oceanographic measurements through EOS-6 Ocean Surface Topography, EOS-5 Ocean Surface Winds, EOS-3 s ocean color capability, and EOS-10 Polar Altimetry.

- The group expressed concern about the detailed implementation of these capabilities in terms of timing, data continuity, calibration, orbital characteristics, and international partnerships.

- They endorsed the ocean salinity component of EX-4, follow-on gravity measurements with EX-5, and the Special Events Imager (OP-6).

Hydrology and Global Water Cycle

- The principal systematic measurement recommendation from this group was the Global Precipitation Mission EOS-9 with the same call as the Applications panel to proceed without waiting for the Japanese ATMOS-A.

- Exploration of soil moisture through EX-4 was endorsed, with a request that the mission not be delayed for technology development in ocean salinity observations.

- A snow and ice exploratory mission was endorsed which appears consistent with the concept of EX-7 Cold Land Processes.

- This group also recommended an additional exploratory mission for measuring river and lake stages.

Atmospheric Chemistry

The report from the Atmospheric Chemistry team was more complex in its response to the NASA nominal scenario, but basically endorsed the discipline breakout group s report.

- In addition to the Stratospheric Composition (EOS-7), they advocated a mission to continue total column ozone and one for ozone profiles (using multiple components in different orbits).

- Within the concept of the EX-1 Tropospheric Chemistry Research Mission, the interdisciplinary team recommended a Global Pollution Mission and a mission to look at the upper troposphere and lower stratosphere.

Solid Earth Science and Natural Hazards

- The Solid Earth Science and Natural Hazards group strongly supported a SAR interferometry mission which could be EOS-8 Topography and Surface Change, giving more detailed specifications for performance than the NASA mission concept.

- The Time-Dependent Gravity Field Mapping Mission EX-5 was endorsed, as well as OP-5 the Volcanic Ash and Gas Emission Mapping Mission from geostationary orbit.

- An additional mission to map the time-varying global magnetic field was proposed as well.

Section 7: COMPARISON OF MISSION SCENARIOS*

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Land Use/Land Cover (10-20 m)	Global Land Cover Inventory Mission (LCTE) (Landsat continuity) should consider including 1-3 m panchromatic band	High Resolution Mission (Harriss)	Many economically important applications in addition to key science. (Harriss) Consider flying Land Use and Global Ecosystem missions together on same platform. (LC/TE)
Climate Variability & Trend —temp, moisture profiles —bridge between PM1 & NPOESS	Variability & Trends in Basic Climate Variables (Smith)	Climate variability and Trend (Tropospheric sounding measurements of temperature and humidity) (Hallgren)	The science questions are reasonably well articulated and address needs that have been expressed by national and international groups. Temperature and moisture observations for detection and attribution of global warming must be more accurate than those planned for the NOAA satellites in the next decade (Hallgren) Atmos. Temp, moisture, and TOA radiation fluxes to fill gap .

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Global Terrestrial and Oceanic Productivity Mission (coarser resolution, bridge between MODIS & NPOESS) could include AGI	Global Ecosystem Productivity (LC/TE) (MODIS continuity)	Moderate Resolution Mission (Harriss)	LC/TE priority concern on AM gap, more important than PM1-> NPOESS. Prefer VIIRS fill-in to allow understanding of instr. and minimal cost. Want to rely on operational systems. Need to know more about foreign plans in 2005+ time frame
	Ocean Color w/AGI (O&I) Advanced Ocean Color Mission (O&I) (not nec. Hyperspectral, but w/high radiometric sensitivity)	Advanced Global Imager (Harriss)	AGI - important bridging mission to continue moderate-resolution multispectral imaging of land and ocean ecosystems in gap between EOS Phase 1 and NPOESS. Will be the fundamental tool for assessing climate-biosphere interactions (Harriss)
		Ocean Color continuity (Tapley)	Morning orbit gap-filler betw. MODIS & VIIRSS. Data quality, orbit etc. important; need one tilting sensor or 2 non-tilting (O&I)
Total Solar Irradiance Monitoring Program	Variability in Solar Forcing (Smith)	Total Solar Irradiance (Hallgren)	The science questions are reasonably well articulated and address needs that have been expressed by national and international groups. (Hallgren) Required continuation between TSIM and NPOESS (Smith)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Ocean Surface Wind	Vector Wind Measurements (O&I)	Vector Wind Measurements (Tapley)	2nd priority for O&I. METOP scatt inadequate. Need bridge betw. ADEOS-2 & NPOES (O&I)
Ocean Surface Topography	Ocean Altimetry (O&I)	Ocean Surface Topography (Tapley)	Continuation of T/P class sea surface topography is highest priority. Cannot justify ANY gap in coverage; orbit is important (O&I)
Stratospheric Composition		Total Column Ozone (Wofsy)	Nadir mapping instrument in polar orbit, following on the various TOMS mission and the ozone column mapper on the EOS-CHEM platform. Long-term calibration needed to define trends of 1%/decade makes this unsuitable for treatment as an operational instrument in the conventional sense. (Wofsy)
		Ozone Profile (Wofsy)	Occultation instrument like SAGE3. Need orbit or set of orbits that provide reasonable scanning of the occultations over a global range of latitudes, at a reasonable frequency. (Wofsy)

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Stratospheric Composition (cont.)		Stratospheric Composition for limited suite of species (Wofsy)	2 Platforms: mid-inclination FTIR and visible occultation instrument attached to the ISS & polar orbiter with microwave/IR emission instruments and occultation instruments. (Wofsy)
Topography and Surface Change	InSAR Surface Deformation —2-satellite L-band mission (SES/NH)	SAR Interferometry (Solomon)	mm-level line-of-sight distance accuracy; 30-100 m positional accuracy, targetability and repeatability of viewing scenes over full range of latitudes. Belongs high on NASA's priority list for systematic measurement. (Solomon)
	High resolution topography, follow-on to ICESAT		Investigate various technologies and commercial partnerships (SE/NH)
Global Precipitation (after ATMOS-A)	Global Precipitation (Smith)	Global Precipitation (Harriss, Bras)	Urgent and high priority from an applications perspective. Planning for this mission should be accelerated. (Harriss) Don t wait for ATMOS-A (Bras) Move up to 2003 (Smith) Synergy with Cloud Radiative Forcing mission — implement in same timeframe w/shared instrument program (Smith)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Polar Altimetry —ice sheet mass detection and balance	Polar Altimetry (O&I)	Polar Ice Mass Change Time Series (Tapley)	Study whether 5-year gap is acceptable (O&I)
Tropospheric Chemistry research Mission		Global Pollution Mission (Wofsy)	Possible instruments include space-borne DIAL and UV and IR nadir sounders/mappers. We envision a strong technology development program in this area to enable a future mission. (Wofsy)
		Upper Troposphere-Lower Stratosphere Mission (Wofsy)	Temperature, ozone and water vapor in the upper troposphere, tropopause region, and lower stratosphere, e.g., upper tropospheric water vapor using microwave limb sounding. Technology development effort needed to mature new methods for quantifying these parameters near the tropopause followed by a lean, low cost space mission. (Wofsy)

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
Aerosol Radiative Forcing Research Mission	Aerosol Radiative Forcing Feedback (Smith)	Aerosol Radiative Forcing research (Hallgren)	Cloud-Radiation Feedback and Aerosol Radiative Forcing Missions require observations of a number of common parameters. Independence of these missions be preserved and the synergism between them be maximized through extensive and intensive early planning (Hallgren) Highest priority for Atm. Climate (Smith). Synergy with global precip. Mission (Smith)
Cloud-Radiation Feedback Research Mission	Cloud-Radiative Forcing Feedback (Smith)	Cloud radiation feedback (Hallgren)	Cloud-Radiation Feedback and Aerosol Radiative Forcing Missions require observations of a number of common parameters. Independence of these missions be preserved and the synergism between them be maximized through extensive and intensive early planning (Hallgren) Dedicated mission w/Active & passive sensors (Smith)

Blue Book	Discipline Panel Recommendations	Interdisciplinary Panel Recommendations	Comments
Soil Moisture & Ocean Salinity Observing Mission	Comprehensive ocean/air interface mission focusing on salinity & soil moisture (O&I) Soil Moisture (Smith)	Soil Moisture (Bras)	Technological challenge but high payoff for salinity measurements w/accuracy of 0.1 to 0.3 PSU can be achieved. (O&I) Don t hold back soil moisture to wait for salinity technology (Smith)
		Ocean Salinity (Tapley)	
Time-dependent Gravity Field Mapping	Temporal Variation of Gravity Field (SE/NH) GRACE follow-on (O&I)	Time-dependent Gravity Field mapping (Tapley, Solomon)	GRACE follow-on mission be placed in the systematic category, due to the value of continuous long-term measurements of temporal gravity field changes (SE/NH) Shd be experimental mission until GRACE results can be evaluated (O&I)
Vegetation Recovery Mission	Ecosystem Response to Disturbance Mission (LC/TE)		possibly involving a combination of remote sensing technologies: lidar, SAR imaging, hyperspatial imaging, simple vegetation index, wide FOV sensor, multi-angle viewing, hyperspectral imaging (LC/TE)
Cold Land Processes Research Mission (snow & ground water) eg L-band SAR	Cold Processes Research (Smith) — snow cover, depth, snow-water equivalence	Snow & ice (Bras)	

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
INSTRUMENTS			
Advanced Microwave Sounder			
Tropospheric Wind Sounder	Tropospheric wind sounder shd be included in Climate Variability mission (Smith)	Tropospheric Wind profiler (Hallgren)	
GPS for Atmospheric Sounding			
Advanced Geostationary Sounder			
Volcanic Ash and Gas Emission Mapping Mission & advanced geostationary Earth Imager	Research geostationary platform for various applications (SE/NH)	Solomon: monitor natural hazards	
Special Event Imager (geo)	SEI for met & hydro observations, also canopy conductance and fire for diurnal sampling (LC/TE) Pointable imager for tidal effects on coastal ecosystems (O&I)	Special Event Imager (Harriss, Tapley)	could potentially provide unique, high frequency observation of episodic processes in terrestrial and coastal ecosystems that are not easily captured by a dedicated mapping mission (Harriss)
Lightning Mapper (geo)			
	Surface Water Measurement — lake and river heights to estimate discharge (Smith)	Measuring River & Lake Stages (Bras)	
	Continued Magnetic Field Measurements (SE/NH)	Time-varying global magnetic field (Solomon)	Continuation beyond 2005 important. Pursue in partnership with foreign scientists, Code S. (SE/NH)
	Orbiting Transfer Radiometer (LC/TE)		

Blue Book	**Discipline Panel Recommendations**	**Interdisciplinary Panel Recommendations**	**Comments**
	Coarse resolution SAR (LC/TE)		
	Multi-angle observation (LC/TE)		
	Mesoscale weather (Smith)		Requires advanced geostationary spacecraft — operational adjunct mission (Smith)

*References are to inputs given at Easton and immediately thereafter:

<u>Interdisciplinary Panels:</u>
Bras: Hydrology and Global Water Cycle
Harriss: Applications
Hallgren: Atmospheric Climate Physics
Solomon: Solid Earth Science and Natural Hazards
Tapley: Oceans & Ice
Wofsy: Atmospheric Chemistry (same report for discipline and interdisciplinary)

<u>Discipline Groups:</u>
LC/TE: Land Cover/Terrestrial Ecology (Janetos)
Smith: Atmospheric Physics, Global Water Cycle and Hydrology
O&I: Oceans and Ice (Freilich)
SE/NH: Solid Earth and Natural Hazards

Section 8:
RECOMMENDATIONS AND CONCLUSIONS

NASA s Earth science enterprise has a strong scientific foundation and a clear justification for continued support. The Easton workshop validated the science and demonstrated that the program continues to address key questions in Earth system science. The review also reinforced the important contribution that continued scientific progress can make in vital areas of public importance.

The process NASA undertook to refine its Earth science mission planning in light of the evolution in scientific understanding was the right thing to do. Changes in technology and advancements in science provided an opportunity to update the program and make it more effective. The 1995 La Jolla review and this 1998 process and workshop are responsive to the National Academy of Science s Pathways report. NASA should be commended on its willingness and dedication in trying to meet the concerns raised by the Academy.

> <u>NASA should be commended for undertaking this review and for developing a more flexible and resilient program paradigm.</u>

The evolution of NASA s program has led to a new paradigm which includes missions selected because they contribute to sustaining long-term measurements to meet defined observing requirements, and experimental missions that address new science areas, either process studies or discovery missions. In addition, NASA proposes to invest in developing new instruments and technology for future missions. The ability to evolve the scientific goals, the technological implementation, and the human and organizational participation in EOS should make the system more resilient over the long term. It is a new, still experimental way to achieve continuity of overall research strategy in a dynamically evolving environment.

The program review highlighted good new subjects that are worthy of serious study for inclusion in EOS, such as aerosols, clouds, soil moisture, and ocean salinity. These were not technically feasible at a low cost when EOS was first conceived but now the technology is within reach and the scientific need is well documented. The NASA mission scenario includes consideration of such missions. At the same time, NASA has identified experimental measurements such as precipitation, which are now ready to be considered for long-term systematic observation. This has resulted in a proposed global precipitation mission in the Blue Book plan. The new scenario also provides for an integrated strategy for the study of tropospheric ozone distribution and chemistry, with a balanced combination of airborne campaigns and global observation from satellites. NASA has also reached out more aggressively to the applications community to broaden the user base and the potential benefits from the nation s investment in the Earth science enterprise. It is clear that the science of the ESE can have an enormous positive impact on many communities not currently engaged in the program, and the attention to applications should help strengthen the communication and the linkages between the science and new end users.

There are areas of serious concern, however, in the new approach. The new freedom and flexibility has added risks of various kinds. These include greater uncertainty in the out years about the continuation of certain measurement series; increased complexity in integrating the various elements of the program into a coherent whole, and increased interdependence in many domains. The hazards are real and the time is short. Once the program is defined, NASA can address some of these issues. Others will require action at a higher level.

The benefits of the new NASA approach come with significant risks. These include uncertainty about continuity of measurement series; increased complexity and interdependence; and more challenges in achieving programmatic integration.

The single most critical concern is the lack of a national policy to address long-term measurements to meet known national and international needs. Some needs are driven by science, such as continued climate studies and improved weather predictions; some will be addressed by already planned operational systems (primarily NPOESS). Some long-term observing requirements stem from commitments made in international treaties such as the Montreal Protocol and the Framework Convention on Climate Change. Others are in areas where ongoing government services can be enhanced by the application of Earth science and space technology such as natural hazards detection and response, management of wilderness areas and agricultural monitoring.

The nation needs to consider the long-term future of the measurements being made or that will be made by the ESE that will demand a commitment beyond the current plans for NASA missions. Attention currently focuses on NPOESS. Here the concerns are twofold. First, for the measurements explicitly accepted as within the NPOESS mandate, there is no assurance that the quality of measurements, including accuracy, calibration, ground validation, and orbital parameters will be able to meet the scientific requirements. Second, there are many other measurements of importance that NPOESS has no mandate to make.

A new national policy is required to ensure the long-term continuity of key datasets needed to meet research, operational, and policy requirements. Without this commitment, NASA may find it difficult to fund new discovery-type missions needed to advance scientific understanding and stimulate technological progress.

A policy framework is needed to support a meaningful discussion of the long-term future of environmental measurements from space. U.S. commitments to the global observing systems (GCOS, GOOS, and GTOS) should be considered in this dialog. The role of other US Government agencies needs to be examined. It is not obvious that NOAA should be the only place to look for long-term sustained observations from space. Governments of other countries have committed to long-term space programs in Earth observation and there is active discussion to develop an Integrated Global Observing Strategy. The existing coordination frameworks that have become increasingly effective in planning weather satellite systems and research missions should be strengthened to encompass the whole suite of needed long-term observations. In addition, there is consideration of private sector roles in ultimately providing observations on a commercial basis and allowing governments to act as consumers. All these issues must be examined and a well-articulated national policy framework developed. This process should start now. The complexities of the situation will require difficult tradeoffs in areas such as sharing of intellectual property rights (between government and private sector and between governments) and reexamination of agency mandates.

Furthermore, there is more to meeting long-term observing requirements than just putting satellites in orbit. To effectively provide useful information, attention and funding must be provided for in situ measurements, and for the needed increases in computational capacity and modeling to integrate data from multiple sources and provide meaningful analysis. It is clear that NASA cannot be the only source for such programs, and that NASA and NPOESS together will not have the breadth and depth to meet the nation s needs. Unless we make a national commitment to sustaining key measurements needed for science, policy, and other applications, NASA will not be able to turn its attention to the unique contribution it can make in advancing the science and technology in Earth observations through discovery-type missions looking at new areas. The success of the Blue Book scenario is dependent on reducing NASA s role in long-term sustained observations through their eventual transition to another budget to free up resources for new missions. The bridging missions are an important and necessary NASA contribution to ensure that we have time to develop the needed policy.

In defining the process or discovery missions, NASA should pay particular attention to the programmatic breadth of the mission concepts to ensure that research in new areas has a fair opportunity for consideration along with more well established concepts. The RFI process can be a good tool, but must be openly and fairly implemented to ensure a breadth of new research opportunities.

The second fundamental concern is the challenge of program integration. The new paradigm is more complex than earlier EOS program approaches. There is an enormous challenge in meeting the goal of understanding the integrated Earth system while assembling observations from a wide range of focussed space-based and in situ observing projects. The policy of PI-led missions, each conceived and implemented in a different institution and subject only to light-touch NASA management, adds to the diversity which can enrich the program but adds to the complexity. Depending for critical measurements on other organizations within the US Government and abroad also introduces risk. Furthermore, providing sufficient computational, data system, and communication resources to support interdisciplinary research may be difficult to define, defend, and achieve.

> By defining a more complex program with a greater number of smaller components and more players, NASA has made it more difficult to achieve an integrated program. Interdisciplinary research may require additional effort to bring together all the needed elements.

The EOSDIS, which was not the subject of review in Easton, was intended to be a fundamental tool in serving the broad Earth science and applications community, and stimulating exchange and interaction among different disciplines and interdisciplinary scientists. When the short-term issues associated with getting the first round data collected, analyzed, and distributed are more clearly resolved, NASA and the community must take stock of the realistic expectations for EOSDIS and consider the evolution of EOSDIS in light of the evolution of the flight system and scientific.

> The data and information system is still a critical element in the Earth science program and needs further examination to ensure that the user communities are able to easily obtain and meaningfully use the data and information acquired in the program.

The social structures such as the Investigator Working Group for EOS and other forums for science community involvement should be examined to see how they can be adapted to the new program environment. NASA needs groups of knowledgeable researchers and representatives of other user groups such as emergency response agencies and operational users who can debate issues , consider tradeoffs, and advise NASA when tough decisions are needed. This will only happen if NASA has the needed administrative and management staff to support such processes.

In conclusion, EOS has become a flexible evolvable system for making measurements pertinent to Earth system science. There are exciting opportunities and formidable challenges ahead. With the support of a strong Earth science community, and the attention of policy-makers, we can expect many new discoveries and great progress in the years to come.